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Plant Level Performance of Coal Fired Public Sector Thermal Power Generation in India

Satvir Singh

Associate Professor, Department of Economics, Arya PG College Panipat, Haryana, India
Email: satviraryapgcollege@gmail.com

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Abstract— *The present paper attempts to measure the plant level performance of 75 coal fired public sector thermal power plants in India for the period 2014-15 to 2017-18 using non parametric approach, Data Envelope Analysis (DEA) with a single output i.e. Power generation and five inputs viz. installed capacity, planned maintenance, forced outages, auxiliary power consumption and specific coal consumption. The performance level of the plants in the study has been categorized into three main groups. The first group includes the plants which have unit efficiency on CRS, VRS and scale efficiency scores, the second group includes the plants with optimal VRS efficiency but lower scale efficiency, and third group includes the plants with less than unit VRS and scale efficiency. The study observed 7 to 8 plants in first group, 21 to 24 in second in second group, and rest in third group. The mean technical efficiency for the period under study varied from 66.1% to 100% under CRS, VRS and Scale efficiency. The study also revealed the differences in plant level performance both at operator and regional level. The mean technical efficiency has remained more or less same with minor fluctuations but the number of thermal power plants with technical efficiency above the mean technical efficiency shows an increasing trend.*

I. INTRODUCTION

Energy is the key source of economic and social development. In the modern business world, production and consumption processes consider the availability of energy as the basic input. Barney, and Franzi (2002) hold that in the modern economy, energy is responsible for almost half of Industrial growth. In a civilized society, the basic amenities of life such as health, education, sanitation, and communications are greatly dependent on the availability of energy services. The lack of energy supply may adversely impact the utilization of resources and slow down the economic development. There is a strong correlation between energy consumption and human well-being. As a result, developmental factors such as education and health will be impeded by energy supply constraints. The important indicator of economic and social development in a country is believed to be the per capita consumption of electricity. The per capita consumption of electricity in India has risen steadily in recent years but it is much below the world average and has wide variations with Bihar being abysmally low, Dadra Nagar, and Haveli being highest.

Prior to independence power sector in India was mainly controlled by Britishers (Kale, 2004) and governed by the electricity act, 1910 which regulated the operations of licenses of electricity companies. Overwhelmed by the historic success of public sector in erstwhile USSR, leaders and planners in India were enthusiased for setting up the big and heavy industries including energy industry under the public sector enterprises. The Indian government, therefore, initiated the steps of nationalization of the electricity sector. The electricity act, 1948 led to the establishment of state electricity boards (SEBs) which were entrusted with triple role of electricity generation, transmission and distribution (Choukroun, 2001). The Act also paved the way for the creation of central electricity authority (CEA) for developing sound adequate national power policy and co-ordinate the activities of concerned planning agencies.

As a result of collective efforts at various levels, presently India is third largest producer and fourth largest consumer of the electricity. As against the total installed capacity of 1362 MW of which 854 MW was from thermal power in December,1947, there has been substantial growth in total installed capacity to 3,86,888 MW of which 2.34,858 MW was from thermal power as on July, 2021. The contribution of coal fired thermal power in total thermal power is around 86%. The share of central government, state government, and private sector in total installed capacity is 26%, 27%, and 47% respectively. During 1960s, India began utilizing grid management to form four regions viz. northern, western, southern, and eastern. The maximum number of coal fired public sector thermal power plants operating in western region were 24 (20 thermal power plants operating under respective state governments and 4 thermal power plants were operating under central government) followed by 21 thermal power plants operating in northern region (14 operating under respective state governments and 7 operating under central government), 18 thermal power plants operating in eastern region (8 operating under respective state governments and 10 operating under central government), and 12 thermal power plants operating in southern region (10 operating under respective state governments and 2 operating under central government) respectively during the period of 2014-15 to 2017-18.

As against the growth of electricity generation in general and thermal power generation in particular, there are certain inherent inefficiencies in the electricity generation as has been highlighted in annual performance reviews of thermal power stations published by Central Electricity Authority. Plant load factor (PLF) which shows the ratio between actual energy generated by the plant to maximum possible energy that can be generated showed a continuous decline from 64.29% (2014-15) to 59.22% (2017-18). The PLF of power plants operated by Central Government has been more than 70% during the same period while of the plants operated by State government had been around 55%. Energy loss due to planned maintenance of plants showed a decline from 4.66% to 4.29% during the period of study, while energy loss on account of forced outrage which has been largely on account of non availability of coal and poor management marked the increase from 19.05% to 25.04% during the same time. There has also been decline in the operational availability of plant from 76.29% to 70.66% during the period of study. Energy losses also accrued on account of various internal and external problems to the tune of more 10% during the same time. However, auxiliary power consumption (ACP) which shows the percentage of electricity consumed in the process of electricity generation showed a decline from 8.02% to 7.57% during the same time period.

Over 1.4 billion people in the world have no access to electricity and India accounts for over 300 million of this number. As per the estimates of international energy agency (IEA), India needs to add between 600gw to 1200gw of additional new power generating capacity before 2050. Keeping in view the above statistics, it is necessary not only to increase the total installed capacity of power but also to plug the inefficiencies, which are inbuilt at micro plant level so that this scarce resource can be utilized optimally. The objective of the present study is the plant level performance evaluation of coal fired public sector thermal power plants in India.

The performance evaluation is a structured process in which an organization can identify, measure, and monitors its processes, systems, and programs. This principle has universal application in all organizations including power sector, manufacturing, agriculture, health, and such other sectors. Hofer (1983) argues that the performance evaluation is an important component of management level decision making processes. The results of evaluation become the basis for management decision in an organization. In case of unsatisfactory results, the problem area can be identified for initiating the mitigation actions. In the production process the concern of every organization is to ascertain how efficiently its resources are utilized. The objective is to link the performance with efficiency. In the light of aforesaid discussion there is ample space for ascertaining the inefficiency at micro plant level and working out the remedial suggestion.

To measure the plant level efficiency of coal based public sector thermal power sectors in different regions of India, we used Data Envelope Analysis (DEA) which is non parametric approach for constructing the efficient frontier. We made use of two models of DEA i.e. CCR Model (Charnes et. al, 1978) and BCC Model (Banker et. al, 1984). The CCR model produces constant returns to scale (CRS) frontier and measures overall efficiency scores and relative efficiency for different DMUs that lies between 0 and 1. The BCC model produces variable returns to scale (VRS) efficiency frontier and DMUs will be efficient only in case it is technical and scale efficient.

The study revealed that DMUs above mean technical efficiency with CRS, VRS and scale efficiency were 59.67%, 55.67% and 56% respectively. We also found that during the entire period 31 thermal power plants exhibited constant returns to scale, 266 exhibited increasing returns to scale and 3 exhibited decreasing returns to scale. It was also observed that thermal power plants operating under central government were more efficient than the plants operating under respective state governments leading us to the conclusion that central government operated plants had greater access to the quality coal, advanced technology and resources along with better management and greater size.

Present paper is organized as follow: Section 2 deals with literature survey on use of DEA approach for measuring technical efficiency of DMUs, Section 3 deals with objectives and hypotheses of study, section 4 discusses research methodology where DEA & its CCR & BCC model are discussed briefly, Section 5 deals with results and discussion followed by conclusions.

II. REVIEW OF LITERATURE

Technical efficiency is a term used to measure the effectiveness with which input are used to produce an output. The firm will be regarded as efficient and occupy position on efficiency frontier if it is producing the maximum output with minimum possible quantities of inputs. The DEA has been extensively used in performance evaluation of DMUs in diverse fields. In case of power sector also, there are number of studies that have used DEA approach in India and abroad. Some Important studies among these are discussed here briefly.

Azadeh. A, et al (2007), employed input oriented BCC model of DEA for the assessment & optimization of 40 Thermal power plants of Iran for the period 1997-2000 with one output and six inputs. Tser Chen et.al(2013) applied DEA model for the assessment of global warming effect and resource utilization of power industries in 73 countries of Asia, Europe, and American continent during the period of 2006-2008. Riaz, K et al (2013), employed input oriented model of DEA for measuring the technical efficiency of 47 energy firms belonging to 8 Asian countries during the period of 2005-2011 with two outputs and three inputs. Ahmad Sadraei Javaheri, Ali Hussain Ostadzad (2014), used DEA model for estimating the efficiency of thermal and hydroelectric power plants in the Iranian provinces during the period of 2010-11with one output and 4 inputs. Shanmugam, K.R., Kulshreshtha, P (2002), **e**mployed stochastic frontier production function for panel data for the measurement of the technical efficiency of 59 thermal power plants distributed in different regions in India during the period from 1994-95 to 1996-97 with a single output and two inputs. Further, Shanmugam, K.R., Kulshreshtha, P (2005), measured efficiency of India's 56 coals based thermal power station for the period 1994-95 to 2001-02 and found that operational efficiency varied across the plants and region. Behera, S.K. et al (2010), study conducting the performance evaluation of India's 74 coal fired thermal power plants over a period from 2003-04 to 2007-08 found that plants in the Southern region are most efficient followed by western & Eastern region. Meenakumari R, Kamraj. N (2008), employed two different DEA Models for evaluating the overall efficiency, technical efficiency, and scale efficiency of 29 states owned electric utilities (SOEUs) in India for the period 2004-05. Jain Shafali et al (2010), **e**mployed DEA approach for measuring the efficiency of 30 state owned power generation companies of India including 8 state electricity Boards (SEBs), 7 power department, and 15 unbundled state owned electricity companies for the period of 2005-06 to 2007-08.

In the context of literature review, several studies measured the efficiency of power plants but no study conducted the efficiency measurement of all the public sector thermal power plants in India which contributes more than 50 % of total thermal generation. The present study attempts to measure the plant level technical efficiency of 75 coal based public sector thermal power plants in India during 2014-15 to 2017-18.

The efficiency measurement of thermal power plants has strong bearing on its advantage with reference to other such plants in power delivery. The thrust of the present study is to develop the benchmark of operation for the comparison of the operation of similar entities called DMUs and find the inefficiencies inherent in them with the policy drive of suggesting remedial measures for their improvement. Authors attempt to test the null hypothesis that all coal based public sector thermal power plants located in different regions of India are technically efficient during the period of study.

III. OBJECTIVES AND HYPOTHESIS OF STUDY

The objectives of the study are based on gaps identified in review of the literature. Following are the objectives of the study:

3.1To measure the technical efficiency of the coal based public sector thermal power plants in India from 20014-15 to 2017-18 based on operator (Central or State Govt.) under which it is managed.

The following null hypothesis has been formulated to work on this objective:

H_{01}: Technical Efficiencies of the thermal plants do not vary across different operator under which it is managed.

3.2To measure the technical efficiency of the coal based public sector thermal power plants in India from 20014-15 to 2017-18 based on regions under which it is located.

The following null hypothesis has been formulated to work on this objective:

H_{01}: Technical Efficiencies of the thermal plants do not vary across different regions under which it is located.

IV. RESEARCH METHODOLOGY

Data Envelopment Analysis, a linear programming technique is relatively a new approach for the performance evaluation of set of entities called Decision Making Units (DMUs). This is a benchmarking method for measuring the relative efficiency of a set of DMUs. It is a non parametric approach for ascertaining the efficient frontier. The distance to the efficient frontier determines the measure of relative efficiency of a set of homogenous firms. To measure the efficiency, the primal version of DEA involves maximizing the ratio of weighted output to weighted inputs which tends to be between zero and one. In the dual version, a virtual firm from linear combinations of peer firms Consuming less input and producing more output is carved out. The output oriented model of DEA involves producing maximum output with given existing inputs while input oriented model involves contracting the input levels to produce at least same level of output. In DEA model, efficient DMU lies on the efficient frontier and DMUs away from the efficient frontier are regarded as inefficient

4.1 Mathematical Formulation of DEA Model

The present study used two models of DEA i.e. CCR model given by Charnes et. al. (1978) and BCC model given by Banker et.al (1984). The CCR model being basic model produces constant returns to scale frontier. The CCR model measures overall efficiency scores and the relative efficiency of different DMUs lies between 0 and 1.

4.1.1CCR Model

Suppose there are **'n'** number of DMUs (j=1,2,…….,n) each consuming **'m'** different inputs to produce **'s'** different output. If DMU_0 consumes x_{i0} amount of input **'i'** to produce $\mathbf{y_{r0}}$ amount of output **'r'**, then

$$\boldsymbol{Relative\ Efficiency = \frac{Vitural\ Output}{Vitual\ Input}}$$

$$\boldsymbol{Efficiency\ of\ Unit\ 0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{x=1}^{m} v_i x_{i0}}}$$

In terms of mathematical programming

$$\boldsymbol{max\ h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}}$$

Subject to constraint

$$\boldsymbol{0 \leq \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \leq 1}$$

u_r, $v_i \geq 0\ \forall$ i and r (i=1,2,……,m) & (r=1,2,…….,s); u_r and v_i are the weights of output and input; y_{r0} and x_{i0} are r^{th} output & i^{th} input of DMU_0. The Dual problem is

$$\textbf{min } \Theta 0 - \in [\textstyle\sum_{i=1}^{m} s_{i0}^{-} + \sum_{r=1}^{s} s_{r0}^{+}]$$

$$\sum_{i=1}^{n} \lambda_j y_{rj} = s_{r0}^{+} + y_{r0}$$

$$\sum_{i=1}^{n} \lambda_j x_{ij} = \theta_0 x_{i0} - s_{i0}^{-}$$

$$\lambda_j, s_{i0}^{-}, s_{r0}^{+} \geq 0\ \forall\ i\ \&\ r$$

$$\boldsymbol{\theta_0 = Efficinecy\ Score\ of\ DMU_0,}$$

$$\boldsymbol{\epsilon = Small\ Positive\ number\ to\ make\ input}\ \&\ ouput\ coefficien$$

$$\boldsymbol{\lambda_j = dual\ weight\ of\ DMUj}$$

$$\boldsymbol{s_{i0}^{-}, s_{r0}^{+} = slack\ variable\ for\ input}\ \&\ output$$

$$I.\ If\ \ \theta_0 = 1\ \&\ s_{i0}^{-}, s_{r0}^{+} = 0, the\ DMUs\ are\ \text{efficient}$$

$$II.\ If\ \ \theta_0 < 1\ \&\ s_{i0}^{-}, s_{r0}^{+} \neq 0, the\ DMUs\ are\ \text{inefficient}$$

4.1.2 BCC Model

Banker, Channes and Cooper developed BCC model by adding convexity constraint $(\sum_{j=1}^{n} \boldsymbol{\lambda_j = 1})$ genrates variable returns to scale (VRS) efficiency frontier. This model evaluates both technical & scale efficiency. The DMU will be efficient only in case it is technical and scale efficient. The Dual DEA for VRS model is

$$\textbf{min } \Theta - \in [\textstyle\sum_{i=1}^{m} s_{i0}^{-} + \sum_{r=1}^{s} s_{r0}^{+}]$$

subject ot the constraints

$$\sum_{j=1}^{n} \lambda_j y_{rj} = s_{r0}^{+} + y_{r0}$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} = \theta_0 x_{i0} - s_{i0}^{-}$$

$$\sum_{j=1}^{n} \boldsymbol{\lambda_j = 1}$$

$$\boldsymbol{\lambda_j \geq 0}$$

$$\boldsymbol{s_{i0}^{-}, s_{r0}^{+} \geq 0\ \forall\ i\ and\ \ r}$$

$$\boldsymbol{\theta_0 = free}$$

The variable λ shown as convexity constraints gives the value of decreasing or increasing return to scale.

$I.\, If \sum_{j=1}^{n} \boldsymbol{\lambda_j} = \mathbf{1}$, *the DMUs shows CRS.*

$II.\, If \sum_{j=1}^{n} \boldsymbol{\lambda_j} >= 1$, *the DMUs shows DRS.*

$III.\, If \sum_{j=1}^{n} \boldsymbol{\lambda_j} < \mathbf{1}$, *the DMUs shows IRS.*

The present study has applied input oriented approach with DEAP 2.1 version of DEA for finding the required results.

4.2 Descriptive Statistics

The present study measures the technical efficiency of 75 coal based public sector thermal power plants across different regions in India for four years from 2014-15 to 2017-18. The thermal power plants included in study in all the four years are same except the increase/decrease in the number of units of the Plants. In different years each plant is considered as decision making units (DMUs). The total number of DMUs in four year period of study is thus 300. The descriptive statistics of different inputs & output variables are shown in Table 1.

Table 1: Descriptive Statistics

Variables	N	Minimum	Maximum	Mean	Standard Deviation
Output					
Electricity Generation	**300**	**193.40**	**37496.00**	**7034.64**	**6264.63**
Inputs					
Installed Capacity	**300**	**62.50**	**4760.00**	**1253.14**	**826.40**
PM	**300**	**0.01**	**46.74**	**5.06**	**5.57**
FO	**300**	**0.25**	**79.25**	**22.89**	**20.76**
APC	**300**	**5.06**	**16.00**	**8.99**	**2.19**
SPCC	**300**	**0.52**	**1.11**	**0.72**	**0.09**

The study used the data published by Central Electricity Authority, Government of India in the form of 'Review of Performance of Thermal Power Stations' for different years. For the performance assessment of Thermal Power Plants in India, there cannot be single performance index. Electricity generation, Installed Capacity, Maintenance Expenditure in the form of Planned Maintenance (PM), and Forced Outrage (FO), Consumption of Coal in the form of Specific Coal Consumption (SPCC) and use of electricity for the generation of electricity in the form of auxiliary power consumption (APC) are used as overall performance indicators in the present study. Electricity generation measured in million units is taken as sole output variable. Since gestation period of power plant is very long, so it is not feasible to have a explicit data on capital cost incurred. Therefore, installed capacity is considered as proxy for capital and included as input variable. The power plants has also to incur certain maintenance expenditure which is broadly of two types i.e. planned maintenance (PM) and unforeseen maintenance which may come as a result of unscheduled forced outage (FO). Loss of electricity generation due to PM and FO is considered as proxy of maintenance expenditure and thus taken as input variables. The use of specific coal consumption (SPCC) measured in kg/kwh is considered as input variable. In addition certain electricity is also consumed by power plants for the generation of electricity. This is auxiliary power consumption & is included after deducting the electricity thus used from total electricity generation. Thus, present study includes generation as output and PM, FO, Installed Capacity, APC and SPCC are used as five input variables.

V. RESULTS AND DISCUSSION

5.1: Efficiency estimates under CRS/VRS/Scale scores

The result for entire study indicates that as many as 31 of 300 (10.33%) DMUs found place on efficiency frontier under CRS, and Scale efficiency scores of 1 while 91 of 300 DMUs (30.33%) found place on efficiency frontier formed under only VRS Score of 1. Sector-wise result indicates that with CRS, and Scale efficiency 16 of 31 DMUs (51.61%) with technical efficiency of 1 operated under central government while 15 of 31 DMUs (49.39%) operated under the state governments. With only VRS scores 44 of 91 DMUs (48.35%) which are placed on efficiency frontier were operating under central government while 42 of 91 such DMUs (52.65%) were operating under the state governments. No thermal power plant operating under state government remained on efficiency frontier for entire period of study. Thus, the ownership is one of the important factors in determining the efficiency of the DMUs. On efficiency front, the central government operated power plants performed better than those operated by the respective state governments. The central government operated thermal power plants performed better than not only state government operated thermal power plants but also performed better than overall percentage of efficient DMUs. The percentage of efficient thermal power plants operated under central government which finds place on efficiency frontier with a unit technical efficiency was 13.04% to 21.74% under CRS/CCR and scale efficiency scores while it was 30.43% to 43.48% under VRS/BCC efficiency scores during the period of study. As against this the percentage of efficient thermal power plants operated under state government which finds place on efficiency frontier with a unit technical efficiency was 5.77% to 9.62% under CRS/CCR and scale efficiency scores while it was 21.15% to 32.69% under VRS/BCC efficiency scores during the period 2014-15 to 2017-18. The higher efficiency percentage of central government operated thermal power plants points towards availability of high quality coal, improved technology and better management of the plant at micro level.

Looking at the regional level, the study observed that under CRS and scale model the technically efficient DMUs ranged from 4.76% to 8.33% (northern),12.5% to 16.67% (western), up to 25%(southern), and 5.66% to 11.11% (eastern) while under VRS model technically efficient DMUs were 9.52% to 8.3328.57% (northern), 29.19% to 33.33% (western), 25% to 50% (southern), and 22.22% to 44.44% (eastern). It is observed that southern region witnessed highest percentage of technically efficient plants both under CRS and VRS models during 2015-16, though there was no technically efficient DMU during 2017-18. The study also noted that central government operated plants performed better on account of availability of high quality coal, improved technology and better micromanagement at plant level.

5.2: Group wise performance of DMUs under CRS/VRS/Scale efficiency.

The performance level of the DMUs under CRS/VRS/Scale efficiency during the period of study can be categorized into three main groups.

Group A

This group includes those DMUs which have unit efficiency on CRS, VRS & Scale Efficiency Scores and are placed on the efficiency frontier. In this group, DMUs has large proportion of output to inputs in comparison with other DMUs.

Group B

In this group we have DMUs which have unit efficiency on VRS efficiency but lower scale efficiency. The DMUs in this group are already technically efficient but with inappropriate scale or limited scales.

Group C

This group includes those DMUs which have less than one VRS and scale efficiency. The DMUs in this group can be divided in two sub groups.

Group C1

First sub group includes those DMUs where VRS efficiency score is higher than that of scale efficiency scores. The DMUs in this subgroup requires not only improving its technical efficiency but also needs to make its production scale optimum.

Group C2

The second sub group includes those DMUs where scale efficiency score are greater than VRS efficiency score. This second sub group requires DMUs to concentrates more on improving its technical efficiency.

5.2.1: Operator wise groups of DMUs under CRS/VRS/Scale efficiency.

In the present study 30.67% of total DMUs operated under central government while 69.33% operated under the state governments during the period of study. Operator wise groups of DMUs under CRS/VRS/Scale efficiency scores are shown in the table 2 during the period of study. On an average 10.67% DMUs belonged to group A in years 2014-15 TO 2016-17 but it declined to 9.33% in the terminal years of the study. On efficiency front, the central government operated thermal power plants performed better than not only state government operated thermal power plants but also performed better than overall percentage of efficient DMUs. The percentage of efficient thermal power plants operated under central government which finds place on efficiency frontier with a unit technical efficiency and included in group A was 13.04% to 21.73% with maximum in the year 2016-17 whereas in case of state government operated DMUs, it was 5.77% to 9.62% with maximum in the year 2015-16 and overall percentage was 9.33% to 10.67% with a decline in the terminal year of study. The DMUs included in this group A acts as benchmark for other DMUs which can adopts their best practices to reach on efficiency frontier.

Group B which includes DMUs with optimal VRS efficiency and less than unit scale efficiency indicates the percentage of DMUs between 13.04% and 26.09% with the continuous in every year of study (central government) followed by 15.38% to 21.15% with the decline in the terminal year of study (state government), and 18.67% to21.33% with low percentage in initial and terminal year of study (overall). Since DMUs included in this group are already technically efficient, so they need to concentrate on scale sizing.

Table 2: Operator wise performance of DMUs under CRS/VRS/Scale scores (in Numbers)

Group	Operator	14-15	15-16	16-17	17-18
A	**Central**	4	3	5	4
	State	4	5	3	3
	Overall	8	8	8	7
B	**Central**	3	4	5	6
	State	11	12	11	8
	Overall	14	16	16	14
C1	**Central**	11	14	10	9
	State	25	30	27	28
	Overall	36	44	37	37
C2	**Central**	5	2	3	4
	State	12	5	11	13
	Overall	17	7	14	17

Group C1 includes the DMUs with less than unit VRS and scale efficiency but VRS efficiency greater than that of the scale efficiency. The state government operated DMUs included in this group shows increasing trend while central government operated DMUs included in this group are declining whereas overall DMUs maintains constant trend. This again shows the resource advantage of central government DMUs compared to such DMUs under state government. The DMUs in this group needs to focus on improving technology along with fixing the proper scales of operations for reaching on to the efficiency frontier.

Group C2 includes the DMUs with less than unit VRS and scale efficiency and scale efficiency greater than that of the VRS efficiency. Present study revealed that there has been mixedtrend in overall as well as DMUs belonging to both the government by adopting methods of better production technology and fixing the scale of operations.

5.2.2: Region wise groups of DMUs under CRS/VRS/Scale efficiency.

Region wise groups of DMUs under CRS/VRS/Scale efficiency scores are shown in the table 3 during the period of study. Overall 10.67% DMUs belonged to group A in years 2014-15 TO 2016-17 but declined to 9.33% in the terminal year of the study. Looking at the regional level, western region has performed better with 12.5% DMUs falling in group A in first three years and 16.67% DMUs in the terminal year of study. However, southern region witnessed the highest percentage (25%) of DMUs falling in this group in 2015-16 and none in 2217-18; 11.11% DMUs belonged to eastern region and 4.21% to 9.52% of DMUs in northern region in group A. The DMUs included in this group A acts as benchmark for other DMUs which can adopts their best practices to reach on efficiency frontier.

Table 3: Region wise performance of DMUs under CRS/VRS/Scale scores (in Numbers)

Groups	Region	2014-15	2015-16	2016-17	2017-18
A	**Northern**	1	1	2	1
	Western	3	3	3	4
	Southern	2	3	1	0
	Eastern	2	1	2	2
	Total	8	8	8	7

B	**Northern**	2	5	3	1
	Western	5	5	4	4
	Southern	4	3	3	3
	Eastern	3	3	6	6
	Total	14	16	16	14
C1	**Northern**	14	15	14	15
	Western	8	14	12	9
	Southern	3	3	4	3
	Eastern	10	12	8	9
	Total	35	44	38	36
C2	**Northern**	4	0	2	4
	Western	8	2	5	7
	Southern	3	3	4	6
	Eastern	3	2	2	1
	Total	18	7	13	18

Group B which includes DMUs with optimal VRS efficiency and less than unit scale efficiency had maximum percentage of DMUs (21.33%) in the year 2015-16 and 2016-17 in group B but declined to 18.67% in the terminal years of the study. Looking at the regional level, eastern region has performed better followed by western, southern, and northern region although number of DMUs in the northern region has declined in the terminal year of study. Since DMUs included in this group are already technically efficient, so they need to concentrate on scale sizing. Hence the state government DMUs can obtain better results by revising the scale of their operations.

Group C1 includes the DMUs with less than unit VRS and scale efficiency but VRS efficiency greater than that of the scale efficiency. Study has revealed that DMUs include in this group are increasing continuously from 2007-08 to 2015-16 but registered a decline of 15.91% in the terminal year of the study. Looking at the regional level, northern region has performed better with the increase of DMUs in this group during period of study followed by western, eastern, and southern region. The DMUs in this group needs to focus on improving technology along with fixing the proper scales of operations for reaching on to the efficiency frontier.

Group C2 includes the DMUs with less than unit VRS and scale efficiency and scale efficiency greater than that of the VRS efficiency. Present study revealed that there has been improvement in overall as well as DMUs belonging to different regions by adopting methods of better production technology and fixing the scale of operations.

5.3: Individual plant wise efficiency estimates.

Looking at efficiency scores of individual DMUs, the study found that Vindyachal STPS remained on efficiency Frontier during the entire period of study and maintained its efficiency towards other DMUs. Sipat TPS also remained on efficient frontier during period of study except in 2017-18 where its efficiency descended due to 2% decline in scale efficiency. Talcher and Rihand TPS also remained on the efficiency frontier except in 2015-16 where their efficiency descended by 15% and 7.5% respectively in CRS model, but it adopted best practices in management and again ascended on efficiency frontier. Similarly, efficiency scores of Talchar STPS and R'Gund STPS which remained on efficiency frontier during 2014-15, 2015-16 declined by 3.3%, 2.8% and 4.2%, 8.1% respectively during 2016-17 and 2017-18 on account of non optimum scale of production. Kakatiya TPS which was on efficiency frontier during 2014-15 witnessed declines in its CRS efficiency by 63.5% during 2015-16 solely on account of inappropriate scale of production took remedial measures and again ascended on efficiency frontier during 2016-17 but could not again maintain it in 2017-18 due to scale efficiency issues. Bhusawal TPS shows mixed trend of efficiency scores where it was on efficiency frontier in 2014-15 but lost its advantage in 2015-16 and 2016-17 and shows ascending trend in 2017-18 but could not reach efficiency frontier due to scale efficiency issues. Mauda, Korba STPS and DSPM shows the ascending trends on frontier due to scale efficiency score during period of study. Singrauli and Farakka STPS shows the mixed trend of efficiency score during the period of study.

Overall average efficiency scores in CRS & VRS model were reduced from 0.698 and 0.911 in 2014-15 to 0.689 and 0.894 respectively in 2017-18. This point towards the fact that same level of electricity can be generated by 31% & 10.6% input reduction in CRS & VRS model. Further, study also observed that in VRS model which measure only pure technical efficiency, the average efficiency scores are greater than the average scores under CRS model. This is because CCR model measures overall technical efficiency while BCC model makes differentiation between pure technical and scale efficiency. Thus, BCC efficiency scores can be interpreted as managerial skills. So, there is enough room for bringing innovation in managerial skills for improving the efficiency of inefficient DMUs.

VI. CONCLUSION AND POLICY IMPLICATIONS

The preceding analysis shows that mean technical efficiency of thermal power plants remained same but the numbers of DMUs above mean efficiency points towards the increasing trend. For the period under study, the DMUs have shown the efficiency in the range from 66.1% to 100%.Thisindicates that electricity generation can be enhanced by proper utilization of exiting capacity without resorting to increasing the capacity. On an average around 34% power generation can be increased without any additional resources. The present study also revealed that the number of efficient DMUs and the average efficiency under both CRS & VRS model declined in 2017-18 as compared to 2014-15. On efficiency front, the Central government operated power plants performed better than those operated by the respective state governments.

For achieving higher efficiency level there is urgent need to pursue vigorously renovation and modernization of thermal power plants and existing generation capacity should be optimally utilized. Alternative approach including change of management may be an option for continuously poor performing thermal power plants. The outcomes of the study are important for improving efficiency and productivity change of the thermal power plants. There is an urgent need of monitoring the plants at micro level regarding excessive use of resources and policy makers should encourage the management of less efficient thermal power plants to adopt the best practices of efficient plants. The state level thermal power plants should emulate the management practices of central government run thermal power plants and vice-versa. The study also holds that it is possible to improve the technical efficiency of thermal power plants and place them on frontier or near to it by varying the scale of operations

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